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Tools for Multidimensional Visualization of Acoustic Modeling Outputs in a Geospatial Environment: Phase 1—Feasibility Results

Colin J. Lazauski
Ryan J. Campbell
NUWC Division Newport

Christopher Damon
Charles LaBash
University of Rhode Island

Joshua M. Frederickson
McLaughlin Research Corporation

Peter August
University of Rhode Island Coastal Institute

NAVSEA WARFARE CENTERS
NEWPORT

Naval Undersea Warfare Center Division
Newport, Rhode Island

PREFACE

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Joseph T. Murphy

Joseph T. Murphy
Head, Physical Operations and Support Department

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Colin J. Lazauski, Ryan J. Campbell, Christopher Damon, Charles LaBash, Joshua M. Frederickson, Peter August

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Improved representation of acoustic model outputs and exploration of methods of multidimensional visualization are key elements of NUWC Division Newport's Mission Environmental Planning (MEP) Program's current three-phase model maintenance and upgrade initiative "Tools for Multidimensional Visualization of Acoustic Modeling Outputs in a Geospatial Environment." Phase 1 of the project, initiated on 26 October 2005, consisted of a feasibility study to evaluate, test, and assess the capabilities of various software packages deemed capable of multidimensional analysis. Through partnership with the University of Rhode Island Environmental Data Center, phase 1 has been completed, the results of which are presented in this document.

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LIST OF ABBREVIATIONS AND ACRONYMS

2-D	Two-dimensional
3-D	Three-dimensional
4-D	Four-dimensional
COTS	Commercial off-the-shelf
CNO	Chief of Naval Operations
EDC	Environmental Data Center
EML	Environmental Modeling Laboratory
GIS	Geographic information system
GOTS	Government off-the-shelf
GUI	Graphical user interface
LFT&E	Live fire test and evaluation
MEP	Mission Environmental Planning
NUWC	Naval Undersea Warfare Center
RDT&E	Research, development, test, and evaluation
REFMS	Reflection and Refraction Multilayered Ocean/Ocean Bottoms with Shear Wave Effects
URI	University of Rhode Island
UTM	Universal Transverse Mercator
ZOI	Zone of influence

TOOLS FOR MULTIDIMENSIONAL VISUALIZATION OF ACOUSTIC MODELING OUTPUTS IN A GEOSPATIAL ENVIRONMENT: PHASE 1—FEASIBILITY RESULTS

1. INTRODUCTION

The Naval Undersea Warfare Center (NUWC) Division, Newport, RI, Mission Environmental Planning (MEP) Program provides a broad spectrum of environmental planning services to the Navy community. The Environmental Modeling Laboratory (EML) within the MEP Program is NUWC's premier center for environmental planning; EML's charter is to provide the Navy with advanced environmental analysis, simulation, and visualization products for environmental planning. EML is tasked with providing innovative effects analyses, geospatial data analysis, and environmental data visualization and mapping to all levels of the Navy involving research, development, test, and evaluation (RDT&E), live fire test and evaluation (LFT&E), and Fleet actions that have the potential to affect the environment.

Improved representation of acoustic model outputs and exploration of methods of multidimensional visualization are key elements of the MEP Program's current three-phase model maintenance and upgrade initiative "Tools for Multidimensional Visualization of Acoustic Modeling Outputs in a Geospatial Environment." Phase 1 of this initiative, begun on 26 October 2005, consisted of a feasibility study to evaluate, test, and assess the capabilities of various software packages deemed capable of multidimensional analysis. Through partnership with the University of Rhode Island (URI) Environmental Data Center (EDC), phase 1 has been completed, the results of which are presented in this document.

2. SOFTWARE SELECTION CRITERIA, REVIEW PROCEDURES, AND INITIAL FINDINGS

2.1 BACKGROUND

EML employs a number of software tools to perform effects analysis. For example, the Reflection and Refraction Multilayered Ocean/Ocean Bottoms with Shear Wave Effects (REFMS) model facilitates evaluating the potential effects of underwater explosions or other noise sources on protected species. Peak pressures, positive impulse effects, and energy flux effects from underwater explosions can be evaluated individually using this approach. The REFMS model requires specific inputs to accurately predict effects from an underwater noise source. Those inputs consist of environmental data, including bathymetry, a representation of the layered water and sound speeds, and benthic data such as compressional wave speed, density, layer depth, and representative bottom type (sediments).

Predicted acoustic results can be compared to thresholds to estimate the zones of influence (ZOIs) for individual events. A ZOI is measured as a range in distance from the sound source and can be used to estimate effects on marine species. The presence of marine species can be estimated using the best available density data for the region within which the modeled test occurs. Using species density data coupled with the ZOI allows estimation of the number of animals impacted by the modeled event. Predicting effects aids the environmental planning process by determining what measures must be taken to minimize/mitigate potential impacts to marine species.

NUWC's EML is seeking to leverage its investment in existing resources by coupling acoustic models with graphical information systems (GISs) in a multidimensional visualization environment. To this end, EML undertook a feasibility study to determine which commercial off-the-shelf (COTS) software products could provide EML with the tools necessary to import acoustic modeling outputs into a user-friendly, Windows-based application for multidimensional visualization.

2.2 SELECTION CRITERIA

EML acousticians regularly use MATLAB software (produced by The MathWorks Inc.) to perform computationally intensive tasks associated with acoustic modeling functions and to produce a variety of two-dimensional (2-D) figures presenting the modeling outputs. The MATLAB programming environment makes this approach cumbersome and time-consuming—thus making it necessary for EML to acquire the capability to quickly and easily represent modeling results using graphics.

The EML staff identified the following six key software capabilities that they considered essential for visualizing acoustic model outputs in a multidimensional, geospatial environment and performing some level of analysis independent of the software used to produce the acoustic results:

- Three-dimensional (3-D) interpolation of values
- 3-D visualization using transparency and color gradients
- Planar slicing
- Plume modeling, including intersecting plumes
- Volumetric analysis of areas, isolines, and plumes
- Compatibility and integration with ESRI ArcGIS products.

EML then evaluated seven COTS software products against these criteria. Based on the results of this initial evaluation, it was possible to eliminate several potential software packages from the subsequent review process. Table 1 lists the seven software packages that were considered and indicates their ability to perform the functions listed.

Table 1. Software Evaluated During the Feasibility Study

Manufacturer	Software Name	3-D Interpolation	3-D Visualization	Planar Slicing	Plume Modeling	Volumetric Analysis	ArcGIS Interface
C-Tech Development Corp.	EVS Pro	Yes	Yes	Yes	Yes	Yes	Yes
ESRI	3D Analyst	No	Yes	Partial	No	Partial	Yes
Interactive Visualization Systems 3D (IVS 3D)	Fledermaus	No	Yes	Yes	No	Yes	No
UNH Data Visualization Research Lab	GeoZui3D	Partial	Yes	No	Yes	No	No
The MathWorks Inc.	MATLAB	Yes	Yes	Yes	No	Yes	No
Golden Software	SURFER 8	Yes	Yes	Yes	No	Yes	No
RockWare	RockWorks 2004	Yes	Yes	Yes	Yes	Yes	No

Only the EVS Pro software package met all of the criteria; however, because it is necessary to compare the capabilities of one software package with those of another to truly assess their capabilities, the RockWorks 2004 software was included in the review. Although the RockWorks 2004 software does not have the ESRI ArcGIS interface capabilities that EVS Pro does, it met all of the other selection criteria. No other software package was selected for further review because of their inability to provide one or more of the identified key capabilities.

Table 1 is not an exhaustive list of all available software that may have multidimensional visualization and volumetric analysis capabilities; it does, however, include the current COTS software packages most commonly used for scientific multidimensional visualization and analysis. It was considered important that the selected software package have a professional track record and reputable user base that would continue to drive product development and refinements.

Additionally, government-funded developments (government off-the-shelf (GOTS)) were not considered within the scope of phase 1 of this project. While some GOTS may be capable of meeting the selection criteria, the complexities associated with application development and maintenance outweigh the potential capabilities offered by some GOTS.

2.3 REVIEW PROCEDURES

Both EVS Pro and RockWorks 2004 were evaluated using a sample data set provided by EML. This data set was representative of acoustic modeling outputs from the REFMS model. The ASCII data set consisted of a linear representation of two parameters: (1) positive impulse measured in psi-ms and (2) and peak one-third-octave band energy flux density measured in dB re 1 μPa^2-s. Table 2 presents the positive impulse values as a function of depth and range (or distance from the acoustic source).

Table 2. Sample REFMS Output

Positive Impulse Value (psi-ms)					
	Depth				
Range (km)	**25 m**	**50 m**	**100 m**	**250 m**	**500 m**
0.1	9.8228	23.711	49.564	73.565	72.084
0.2	6.7329	8.9824	14.382	32.876	39.735
0.3	4.9314	6.24	8.9621	19.184	27.417
0.4	3.7403	4.8974	6.9428	13.55	19.724
0.5	2.967	3.9135	5.9268	10.339	15.542
1	0.9847	1.2308	2.0648	2.978	5.7662
2	0.3657	0.6258	1.885	0.2642	1.4131
3	0.2684	0.2463	0.4328	0	0.1018
4	0.3601	0.3962	0.7818	0.3051	0.0515
5	0.1015	0.1444	0.3415	0	0

For the purposes of multidimensional visualization of this data set, it was assumed that the range value is representative of radial propagation from the acoustic source. The data set also contained geospatial reference data that were used to further test the ability of both EVS Pro and RockWorks 2004 to import coordinates associated with the ASCII data set in a variety of coordinate systems ranging from latitude/longitude (degrees, minutes, and seconds) to Universal Transverse Mercator (UTM) (meters).

2.4 INITIAL FINDINGS

The ASCII data were restructured into a format that could be imported into the software environment. Additionally, coordinate values were added to allow geospatial display, which means the acoustic source can be located at a specific point on the Earth's surface (see figure 1). Each software package was then used to process the data. During this step, each of the previously defined criteria was evaluated, thereby assessing the effectiveness of each software package to meet the requirements.

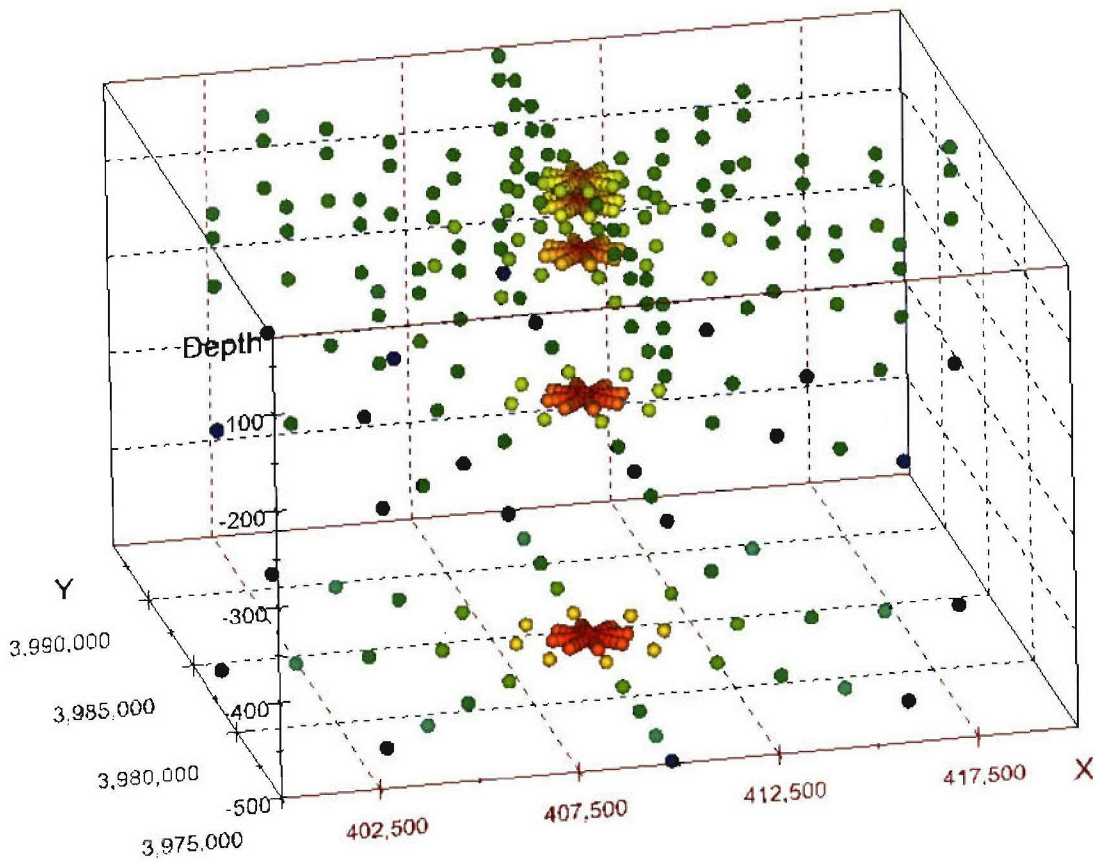

Figure 1. Three-Dimensional Geospatial Display of Data
(All data points are associated with a unique X-, Y-, and Z-Location;
in this particular data set, XY is in terms of UTM meters.)

While both software packages were able to address nearly all of the multidimensional visualization and analysis capabilities, it became apparent that the capabilities of the EVS Pro software far exceeded those of the RockWorks 2004 in all areas. RockWorks 2004 had a very limited predefined toolbox of volumetric analysis functions, whereas EVS Pro included a lengthy list of predefined volumetric utilities. Additionally, the EVS Pro software package exhibited a very straightforward method of outputting any object to a 3-D ESRI shapefile (.shp); it is, in fact, the only software package capable of doing so.

Some additional features of the EVS Pro software package that precluded consideration of RockWorks 2004, or any other software package, included its ability to (1) import Microsoft Access database files, (2) import Visual Basic for applications integration, and (3) model and visualize environmental change over time, giving it a full four-dimensional (4-D) visualization capability.

Based on these initial findings, further evaluation of RockWorks 2004 was discontinued, and phase 1 of the project continued to focus solely on the EVS Pro software package and its ability to satisfy the selection criteria.

3. EVALUATION OF EVS PRO SOFTWARE

The EVS Pro software was evaluated for its ease-of-use and its ability to meet the previously defined selection criteria.

3.1 GRAPHICAL USER INTERFACE (GUI)

A software package's ease-of-use was not identified as a critical selection factor, yet it is still an important factor to consider. The EVS Pro GUI excels in providing users with a logical, visual workflow through the use of an interactive flow chart that automatically updates based on user input (see figure 2).

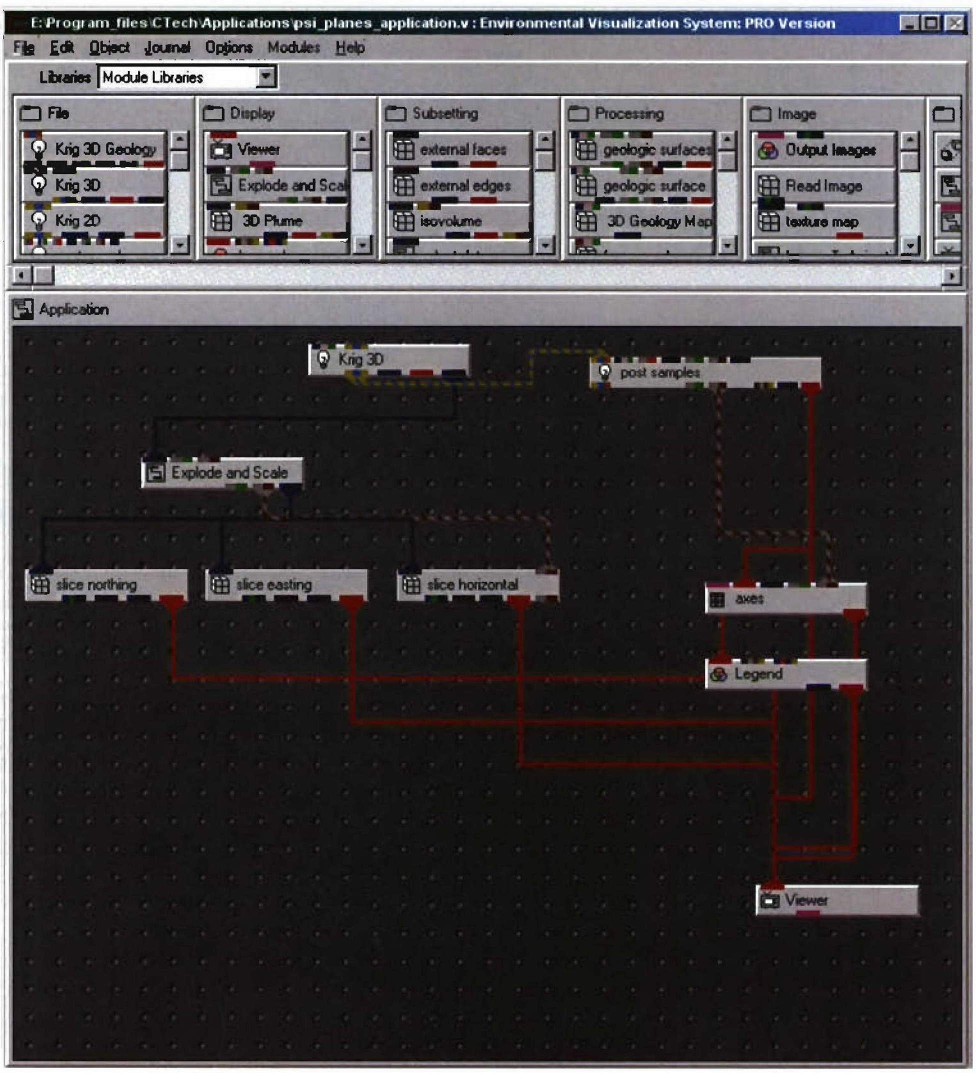

Figure 2. EVS Application Window

Figure 2 is an example of how a project might be visually organized in the EVS Pro GUI. Available EVS Pro tools are arranged by group at the top of the window and are represented as buttons. A user simply drags the tool from the menu into the lower application window to include the tool's functionality in the active project. Each tool represents a predefined visualization or analysis function, allowing properties of each to be edited to produce desired results, be it the visualization of a surface, visualization of a plume, or derivation of a plume's volume.

Additionally, each tool is connected in a logical way that allows data to flow from the input ASCII file, through each of the visualization/analysis tools, and ultimately into the output visualization viewer. This type of interface provides users with increased functionality while minimizing any need for application programming.

3.2 3-D INTERPOLATION

EVS Pro excels in spatial interpolation using kriging algorithms. Kriging, a method of spatial interpolation, estimates unknown values of a variable at unsampled points by using measured values from other points. Honoring of measured data—an essential element of accurate spatial interpolation that EVS Pro addresses very effectively—is the process by which predicted concentrations are precisely matched to actual data. EVS Pro creates a multidimensional grid that assigns nodes matched to the coordinates of the input (measured) data. Through this method, the predicted distribution approaches the actual data as nodes approach measured sample locations. Figure 3 is a visual representation of a 3-D grid used for 3-D interpolation.

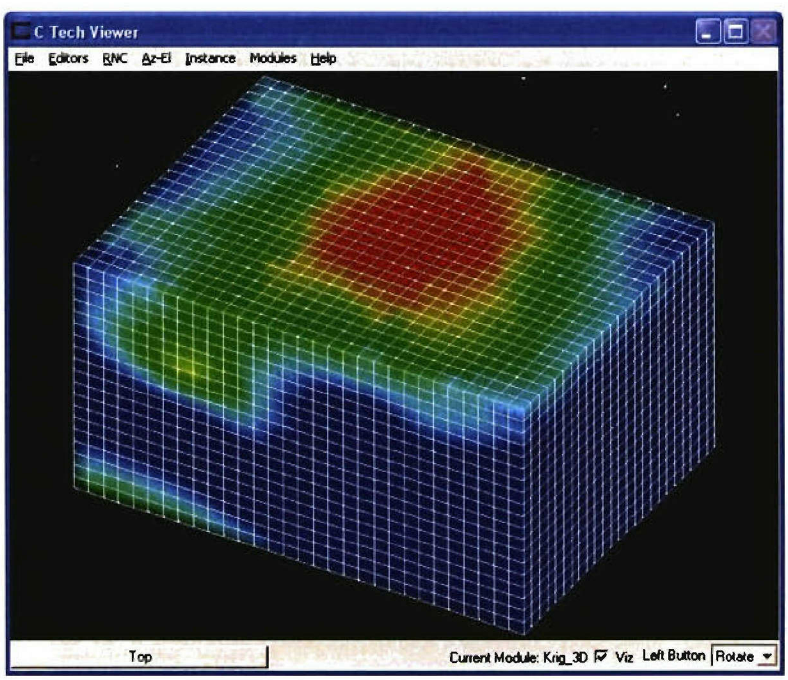

Figure 3. 3-D Grid Example

3.3 3-D VISUALIZATION

EVS Pro offers a multitude of methods to visualize data in three dimensions. The options supported include user-defined color mapping, transparency for all graphical objects, interactive 3-D fence diagrams, drape lines on surfaces, solid contouring, and other vector visualization tools as shown in figure 4.

Additionally, EVS Pro has the capability to automate repetitive visualization tasks and can create and export animated visualizations as movies. For example, EVS Pro (1) can automate the creation of time-series animations and subsequently export the images to a variety of output formats and (2) can produce 4-D interactive models that can be played back on both C-TECH proprietary and freeware players through export capabilities to standard .avi, .mpg, or .hav formats.

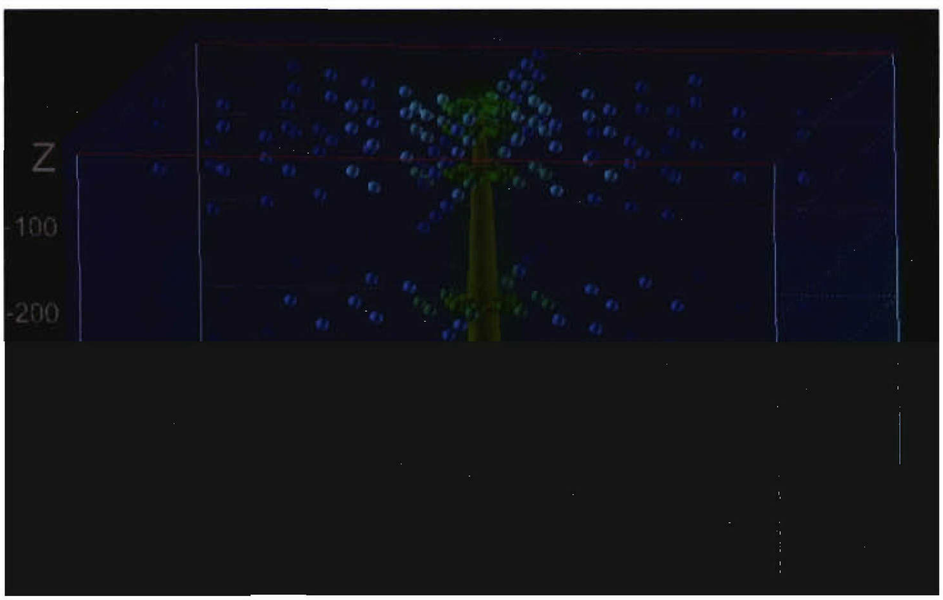

Figure 4. Transparency Visualization Example Showing Input Points, 3-D Interpolated Model, and Two Isosurfaces

3.4 PLANAR SLICING

EVS Pro allows users to work with individual planes or "slices" passing through the model. This process involves two primary steps. First, the software imports the data points as calculated by the REFMS model, generating a 3-D interpolation across the study area. The user can modify the algorithm and parameters used to generate the 3-D surface. Slice planes are then computed based on user inputs and can be placed at any X-, Y-, or Z-value (see figure 5). While the X- , Y- , and Z-slices are either horizontal or vertical, the user also has the option of viewing a slice through any portion of the model and at any angle. In addition, contour lines can be generated for any surface (see figure 6).

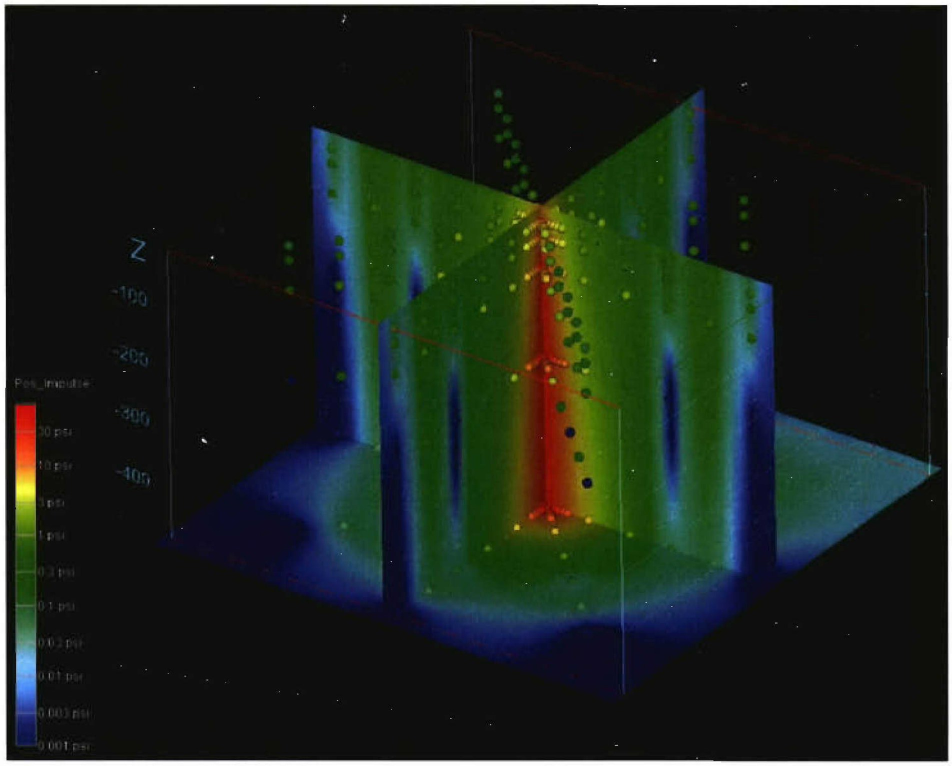

Figure 5. Visualization of Planar Slices

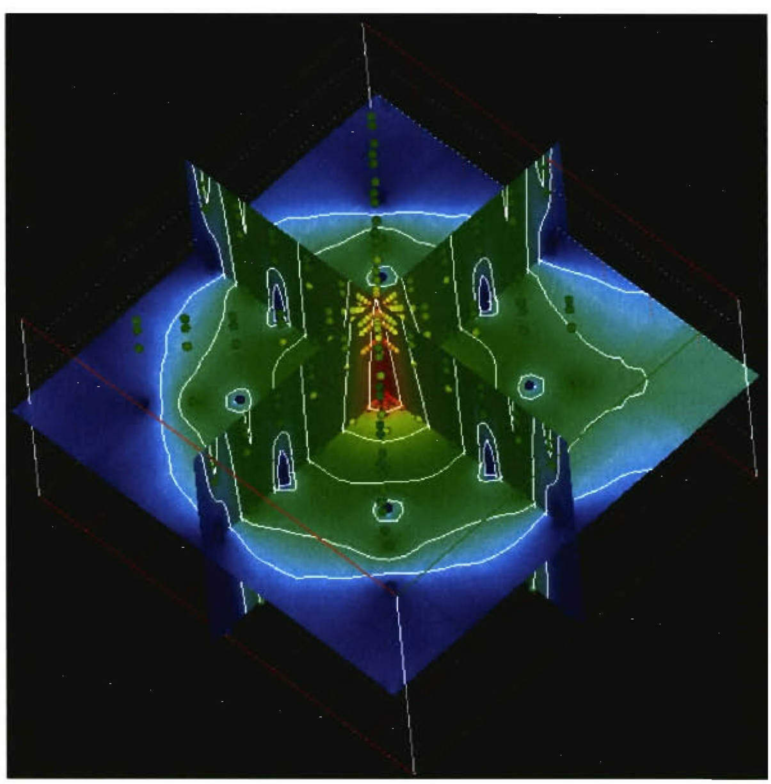

Figure 6. Visualization of Contoured Planar Slices

3.5 PLUME MODELING

Developing isosurfaces or plumes proceeds in a manner similar to that for planar slicing. The software interpolates a 3-D surface, which is then subset to identify the desired level or range of levels. As with the planar slices, contours can be interpolated within the plume (figure 7).

As was seen with the transparency example in figure 4, any number of isosurfaces can be displayed at the same time. Added to the multiple-surface display is the ability to compute the intersection of multiple plumes, calculate volumetrics, and export all plumes, surfaces, and contours as a series of X- ,Y- , and Z-coordinates for other applications.

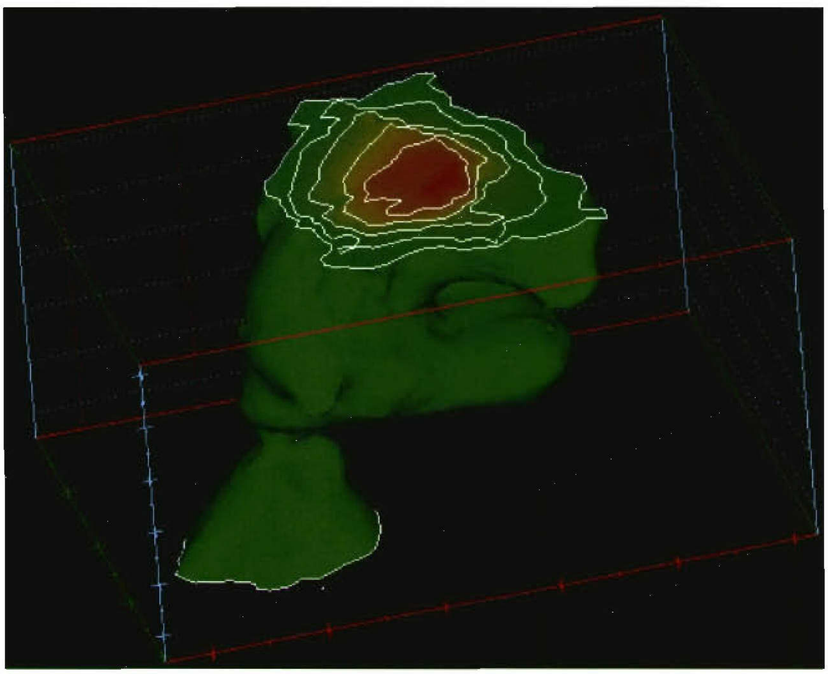

Figure 7. Visualization of an Isosurface, or Plume, with Contours
(Data for this visualization were derived from demonstration data provided by C-TECH.)

3.6 VOLUMETRIC ANALYSIS

EVS Pro uses a suite of tools to numerically calculate area and volume—if a surface can be derived from the 3-D model (plume, planer slice, contour sets, etc), the software can calculate the amount of enclosed space. Meaningful output, however, requires some preplanning before importing data into EVS.

All area and volume calculations reference the "unit" values of the coordinate system, so it is important to select a coordinate system that has meaningful values when the calculations are performed. For this work, the UTM coordinate system was used for spatial reference; therefore, area values are in square meters and volume is in cubic meters. Had a geographic coordinate system been used (latitude, longitude), area and volume values would have been represented as meaningless square or cubic decimal degrees, respectively. The importance of properly defining coordinate systems is also critical with respect to GIS compatibility.

3.7 GIS INTEGRATION

Complete multidimensional geospatial visualization is problematic with the current technology: no single software package can accomplish all the tasks in an adequate manner. A GIS is an effective tool for geospatial visualization and analysis, yet it falls decidedly short with the introduction of the third (elevation/depth) and fourth (time) dimensions. True 3-D software, on the other hand, provides unparalleled visualization and analysis for multidimensional data at the expense of standard cartographic tools. Output from the REFMS model, therefore, necessitates a blending of technologies to extract the most information from the data.

The EVS Pro software has been designed to be fully compatible with the ArcGIS platform, allowing each software package to capitalize on its strengths: EVS Pro for 3-D interpolation, volumetrics, and visualization, and ArcGIS for data subsets, queries, spatial analyses, and mapping (see figure 8). Highlights include the ability to:

- Launch EVS Pro software from within ArcGIS
- Query ArcGIS shapefiles and automatically generate EVS Pro input files
- Read and write ArcGIS 2-D and 3-D shapefiles
- Export interpolated points, plumes, and surfaces
- Export high-resolution presentation-level graphics.

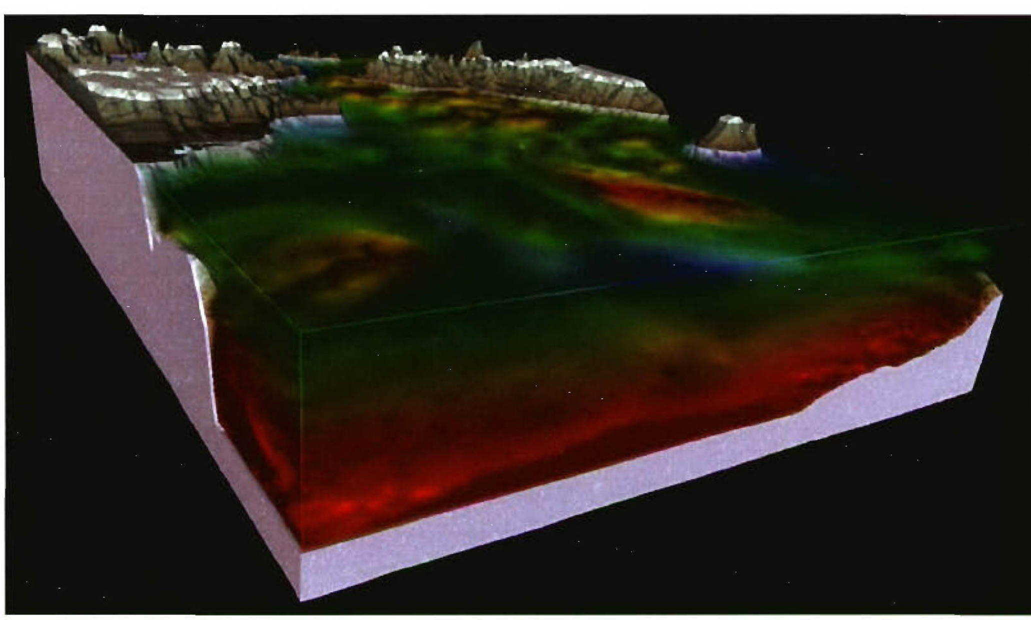

Figure 8. Geospatial 3-D Visualization of Interpolated Oceanographic Salinity Data Coupled with Bathymetric and Terrain Data (Data for this visualization were derived from demonstration data provided by C-TECH.)

Though GIS software often includes some visualization capability, it often falls short when compared with true 3-D visualization software; however, some GIS software, specifically the ESRI ArcGIS suite, has the ability to store, integrate, and display images and animations created using other software applications. ArcGIS recognizes a variety of image and animation formats, including .jpg, .bmp, .tif, .mpg, .avi, and .mov. These images or animations can be displayed selectively by integrating files into the ArcGIS layout as necessary. In this manner, GIS software can become the repository for detailed visualizations performed on small scales that are portions of a project larger in scale and/or size. Additionally, with GISs such as ESRI's ArcMap, images and animations can be hot-linked to objects associated with the GIS project that are accessible via the Internet, allowing them to be viewed using a Web browser, such as Microsoft Internet Explorer.

4. CONCLUSIONS

The NUWC EML is seeking to leverage its investment in existing resources by coupling acoustic models with GIS in a multidimensional visualization environment. The basis of this study was to determine the capability of COTS software products to provide EML with the tools to import acoustic modeling outputs into a user-friendly, Windows-based application for multidimensional visualization.

After a preliminary evaluation of seven COTS products, it was determined that only two products could meet the selection criteria established by NUWC Division Newport; those products were EVS Pro and RockWorks 2004. While both software packages met nearly all of the multidimensional visualization and analysis requirements, it became apparent that the capabilities of the EVS Pro software far exceeded those of RockWorks 2004 in all areas. RockWorks 2004 had a very limited predefined toolbox of volumetric analysis functions, whereas EVS Pro included a lengthy list of predefined volumetric utilities. Additionally, the EVS Pro software package exhibited a very straightforward method of outputting any object to 3-D ESRI shapefiles (.shp) and was the only software package capable of doing so. Some additional features of the EVS Pro software package that precluded consideration of RockWorks 2004, or any other software package, included EVS Pro's ability to import Microsoft Access database files and Visual Basic for applications integration and its ability to model and visualize environmental change over time, giving a full 4-D visualization capability.

Based on these initial findings, further evaluation of RockWorks 2004 was discontinued and phase 1 of the project continued to focus solely on the EVS Pro software package and the ability of the software to address each of the selection criteria. After extensive evaluation of its capabilities, it was concluded that the EVS Pro software met the criteria established by NUWC Division Newport; moreover, it was determined that EVS Pro had additional capabilities to potentially mirror some functions or routines associated with the acoustic modeling process employed by NUWC acousticians. While these capabilities were not within the scope of this study, the volumetric analysis tools available in EVS Pro could be further evaluated to determine if the postprocessing effort required by EML acousticians to develop visual representations of acoustic modeling outputs could be reduced.

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